



Europäisches Patentamt  
European Patent Office  
Office européen des brevets



Publication number: **0 635 929 A1**

(12)

**EUROPEAN PATENT APPLICATION**  
published in accordance with Art.  
158(3) EPC

(21) Application number: **94905244.3**

(51) Int. Cl.<sup>6</sup>: **H02K 37/04**

(22) Date of filing: **01.02.94**

(86) International application number:  
**PCT/JP94/00140**

(87) International publication number:  
**WO 94/18744 (18.08.94 94/19)**

(30) Priority: **01.02.93 JP 36058/93**

(43) Date of publication of application:  
**25.01.95 Bulletin 95/04**

(84) Designated Contracting States:  
**DE FR GB IT NL**

(71) Applicant: **MINEBEA CO., LTD.**  
**4106-73,**  
**Ohazamiyota,**  
**Miyota-cho**  
**Kitasaku-gun,**  
**Nagano 389-02 (JP)**

(72) Inventor: **YOSHIMURA, Noriyuki, Minebea Co.**  
**Ltd.**  
**Karuizawa-seisakushonai,**  
**4106-73,**

**Ohazamiyota**  
**Miyota-cho,**  
**Kitasaku-gun,**  
**Nagano 389-02 (JP)**  
Inventor: **YOSHIDA, Kenji, Minebea Co. Ltd.**  
**Karuizawa-seisakushonai,**  
**4106-73,**  
**Ohazamiyota**  
**Miyota-cho,**  
**Kitasaku-gun,**  
**Nagano 389-02 (JP)**

(74) Representative: **Jackson, Peter Arthur et al**  
**GILL JENNINGS & EVERY**  
**Broadgate House**  
**7 Eldon Street**  
**London EC2M 7LH (GB)**

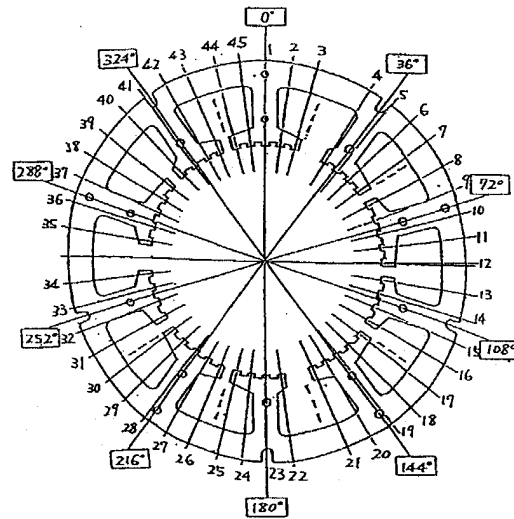
(54) **METHOD FOR DRIVING STEPPING MOTOR OF MULTIPHASE HYBRID TYPE.**

(57) A motor improved in the torque stiffness, and reduced in the resonance vibration when the motor rotates. The fixed magnetic poles each have two or more small teeth which are arranged at the same interval as the tooth pitch of the rotor. The total number (NS) of small teeth of the stators of an asymmetrical type is determined by  $NS = 5 \times (n0 + n1)$  (where n0 is the number of small teeth of each of five fixed magnetic poles, and n1 is the number of small teeth of the other five fixed magnetic poles). The stators of asymmetrical type having n1 small teeth are arranged between the stators of

asymmetrical type having n0 small teeth. The stators of asymmetrical type having the n0 small teeth are arranged on the side opposite to the stators of asymmetrical type having n1 small teeth across the shaft, respectively. In the winding wound on the asymmetric stator, N and S poles are generated. In both full-step and half-step modes, the numbers of the N and S poles are equal because of the magnetization of the poles in each step. In all the steps there are a pair or more of S poles which are adjacent to each other.

**EP 0 635 929 A1**

Fig. 3



STRUCTURE OF ASYMMETRIC STATOR

shift angle  $1/5 T_p$ , and  $N_r = 50$   $N_s = 45$   
 small slot having three intervals  
 small slot having seven intervals

## PRIOR ART

The present invention relates to an improved method of driving a 5-phase hybrid stepping motor.

## BACKGROUND OF THE INVENTION

Hybrid stepping motors have been well known for over a quarter of the century as actuators appropriated for highly accurate positioning movements. The hybrid stepping motors are widely used in various machine tools, e.g. with fully automated production lines, as well as computer related instruments including printers, plotters, facsimile machines, and disk drive units.

For increasing the versatility in use, there is made an attempt to minimize the step angle of such a hybrid stepping motor. To this respect, four- and five-phase types of the stepping motor are now commonly provided.

The conventional four- or five-phase stepping motors however have some disadvantages that torque stiffness is unstable, that static torque is varied depending on the stop position, and that the step angle is not at a high accuracy. It is an object of the present invention to eliminate the foregoing disadvantages.

## SUMMARY OF THE INVENTION

For achievement of the above object, a method of driving a multi-phase hybrid type stepping motor which has a rotor provided with one or more permanent magnets magnetized in the rotating direction of a rotary shaft, according to the present invention, is characterized by a two pole caps mounted to both ends of the permanent magnet respectively, each the pole cap made of a soft magnetic material and having a plurality (NR) of teeth arranged at equal intervals on the circumferential surface thereof, the teeth of the two pole caps being displaced by 1/2 of the teeth pitch (1/2 Tp) from each other, a plurality of stator segments of an asymmetrical form disposed around the rotor, each the asymmetrical stator segment having ten fixed magnetic poles thereof extending inwardly and radially, each the fixed magnetic pole having a winding wound thereon with no taps and being provided with two or more small teeth arranged at equal intervals of the same pitch as of the teeth of the rotor, the total number (NS) of the small teeth of the asymmetrical stator segment being determined by  $NS = 5 \times (n_0 + n_1)$ , where  $n_0$  is the number of the small teeth on each of five of the ten fixed magnetic poles and  $n_1$  is the number of the small teeth on each of the remaining five fixed magnetic poles, the fixed magnetic poles with the  $n_1$  small teeth being arranged alternate with the

fixed magnetic poles with the  $n_0$  small teeth, the  $n_1$  small teeth pole and the  $n_0$  small teeth pole being disposed opposite to each other about the axis of the rotary shaft, the relation between the total number (NR) of the teeth of the rotor and the total number (NS) of the small teeth of the stator segment being expressed by  $NS \geq 20.8 \cdot NR$  (NS being greater than or equal to  $0.8 \cdot NR$ ), a difference between NR and NS being calculated from  $NR - NS = K(S_0 - S_1) + 10(S_1 - 1 + B)$  where K is an integer from 2 to 5,  $S_0$  and  $S_1$  are smallest possible integers or may be equal, and B is a fraction of 1 so that 10B (ten times of B) is always an integer, the ten stator windings on their respective fixed magnetic poles being coupled to one another in a circular order of P3, P8, P5, P10, P7, P2, P9, P4, P1, and P6, five terminals disposed between P6 and P3, P8 and P5, P10 and P7, P2 and P9, and P4 and P1 respectively, and by polarization of the ten fixed magnetic poles at each step of the rotating movement, N and S poles of the same number being generated and one or more pairs of the adjacent fixed magnetic poles being turned to S.

## BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a cross sectional view showing one embodiment of the present invention; Fig. 2 is a longitudinal sectional view of the embodiment of the present invention; Fig. 3 is a front view of a stator system another embodiment of the present invention; Fig. 4 is a vector diagram of a rotor in the embodiment of the present invention; Fig. 5 is a wiring diagram according to the embodiment of the present invention; Fig. 6 is a chart showing the magnetic shift at fixed magnetic poles in full-step mode; and Fig. 7 is a chart showing the magnetic shift at the fixed magnetic poles in half-step mode.

## THE PREFERRED EMBODIMENTS OF THE PRESENT INVENTION

Preferred embodiments of the present invention will be described in more details referring to the accompanying drawings.

Figs. 1 and 2 illustrate in cross section a stepping motor according to the present invention. Fig. 1 is a cross sectional view taken along the line extending at a right angle to a rotary shaft 4. As shown, a stator 1 has ten fixed magnetic poles S, S' arranged inwardly thereof. The fixed magnetic pole S or S' has a stator coil 2 wound thereon and is provided at inward end with a set of small teeth 3. It is assumed that the total number of the small teeth 3 is NS. The rotary shaft 4 has a rotor 5 mounted at center thereto. The rotor 5 has a permanent magnet 7 mounted to the axial center thereof and two rotor caps 8 fitted to both sides of

the magnet 7 respectively, as best shown in Fig. 2. The rotor caps 8 have a plurality of teeth 6 provided on the circumferential surface thereof. It is now assumed that the total number of the teeth 6 is NR. Fig. 1 is a cross sectional view taken along the line A-A of Fig. 2. The ten stator coils 2 are numbered from P1 to P10.

A first embodiment of the present invention is intended to have a five-phase stepping motor with the ten fixed magnetic poles S, S' improved in the torque stiffness, the step angle precision, and the efficiency of movement when  $NR=50$  (where a shift angle between two adjacent fixed magnetic poles is  $1/5T_p$ ,  $T_p$  being a pitch of the small teeth 3). In particular, the number of the small teeth 3 of each alternate one of the ten fixed magnetic poles is increased by one while that of the other fixed magnetic poles is kept 4 (forming an asymmetrical fixed magnetic pole arrangement of the stator). Accordingly, the 4-teeth fixed magnetic pole S is disposed opposite to the 5-teeth fixed magnetic pole S' (Fig. 3).

The difference of the teeth between the rotor 5 and the fixed magnetic poles S, S' is 5 (as calculated by subtracting  $4 \times 5$  from 50 and then,  $5 \times 5$  from the result).

This embodiment also offers an improvement in the stability at torque equilibrium position. The reason is that while at least two adjacent fixed magnetic poles are polarized to N, other two adjacent fixed magnetic poles are turned to S (Fig. 6).

As compared with the first embodiment in which the improvement in the four different respects is ensured with the rotor having 40, 50, 80, 90, or 100 of the teeth, using such an asymmetrical arrangement of the ten fixed magnetic poles of the stator, a second embodiment is characterized by the shift angle between two adjacent fixed magnetic poles which is equal to  $3/10 T_p$  or  $7/10 T_p$ . Equally, the number of the small teeth 3 of every alternate one of the fixed magnetic poles is increased by one.

For determining an optimum degree of the step angle for performance of a stepping motor, the difference of teeth between the rotor and the stator is preferably 5 or 3.

As shown in Fig. 4, a radial stress exerted on the rotor caps is divided into three directions. The stress is evenly applied to the two rotor caps. The three directional components of the stress may less affect the manufacturing tolerance. Thereby, the step angle accuracy will increase and unwanted vibration will be reduced. This is because there are provided only three large distanced slots between the fixed magnetic poles. Fig. 6 shows the polarization of the fixed magnetic poles during a series of 20 consecutive steps. The full 20 steps perform one rotation of the rotary shaft 4. As apparent from

Fig. 6, the number of N poles is identical to the number of S poles in the stepping motor at every position or step. This results in reduction of the hysteresis.

The step-by-step rotating movement will now be described referring to Figs. 5 and 6. Fig. 5 is a wiring diagram according to the embodiment of the present invention. The ten fixed magnetic poles are coupled to one another in a circular order of P3, P8, P5, P10, P7, P2, P9, P4, P1, and P6. Five, blue, red, orange, green, and black colored, terminals are provided between P6 and P3, P8 and P5, P10 and P7, P2 and P9, and P4 and P1 respectively. Fig. 6 is a diagram showing the polarization of the fixed magnetic poles in a full step mode. The dots in Fig. 5 represent the direction of coil windings.

Each of the blue, red, orange, green, and black colored terminals is coupled to a two-throw switch which normally stays in the neutral mode and is turned to one position for connecting to a positive source and to the other position for connecting to a negative source, although its switching circuit is not shown in Fig. 5. The switch is selectively connected to one of the three positions by a command signal from an unshown control unit. Accordingly, the ten magnetic poles are energized to have polarities as shown in Fig. 6 at each step. The switching action at the step produces the two polar states of the same number where at least two adjacent magnetic poles are polarized to S.

Fig. 7 is a diagram showing the polarization of the fixed magnetic poles at the steps in a half step mode.

As set forth above, the present invention with the foregoing arrangement allows the torque stiffness to be stable, the static torque to be equilibrated, and the step angle to be at high accuracy. In the full step mode, the S and N poles of the same number are produced and also, at least two adjacent fixed magnetic poles are polarized to S at each step of the movement. This will minimize abnormal vibration during the rotating movement.

#### APPLICABILITY TO INDUSTRIAL USE

As the specific teeth arrangements of the rotor and the stator are provided in a combination, the static torque acts in equilibrium and the step angle stays at high accuracy. In addition, the S and N poles become equal in the number in both the full and half step modes, abnormal vibration during the rotating movement will be minimized.

#### Claims

1. A method of driving a multi-phase hybrid type stepping motor which has a rotor provided with

one or more permanent magnets magnetized  
 in the rotating direction of a rotary shaft, char-  
 acterized by a two pole caps mounted to both  
 ends of the permanent magnet respectively,  
 each the pole cap made of a soft magnetic  
 material and having a plurality (NR) of teeth  
 arranged at equal intervals on the circumferen-  
 tial surface thereof, the teeth of the two pole  
 caps being displaced by 1/2 of the teeth pitch  
 (1/2 Tp) from each other, a plurality of stator  
 segments of an asymmetrical form disposed  
 around the rotor, each the asymmetrical stator  
 segment having ten fixed magnetic poles  
 thereof extending inwardly and radially, each  
 the fixed magnetic pole having a winding  
 wound thereon with no taps and being pro-  
 vided with two or more small teeth arranged at  
 equal intervals of the same pitch as of the  
 teeth of the rotor, the total number (NS) of the  
 small teeth of the asymmetrical stator segment  
 being determined by  $NS = 5 \times (n_0 + n_1)$ , where  
 $n_0$  is the number of the small teeth on each of  
 five of the ten fixed magnetic poles and  $n_1$  is  
 the number of the small teeth on each of the  
 remaining five fixed magnetic poles, the fixed  
 magnetic poles with the  $n_1$  small teeth being  
 arranged alternate with the fixed magnetic  
 poles with the  $n_0$  small teeth, the  $n_1$  small  
 teeth pole and the  $n_0$  small teeth pole being  
 disposed opposite to each other about the axis  
 of the rotary shaft, the relation between the  
 total number (NR) of the teeth of the rotor and  
 the total number (NS) of the small teeth of the  
 stator segment being expressed by  $NS \geq 0.8 \cdot NR$   
 (NS being greater than or equal to 0.8-  
 NR), a difference between NR and NS being  
 calculated from  $NR - NS = K(S_0 - S_1) + 10(S_1 - 1 + B)$   
 where K is an integer from 2 to 5,  $S_0$   
 and  $S_1$  are smallest possible integers or may  
 be equal, and B is a fraction of 1 so that 10B  
 (ten times of B) is always an integer, the ten  
 stator windings on their respective fixed mag-  
 netic poles being coupled to one another in a  
 circular order of P3, P8, P5, P10, P7, P2, P9,  
 P4, P1, and P6, five terminals disposed be-  
 tween P6 and P3, P8 and P5, P10 and P7, P2  
 and P9, and P4 and P1 respectively, and by  
 polarization of the ten fixed magnetic poles at  
 each step of the rotating movement, N and S  
 poles of the same number being generated  
 and one or more pairs of the adjacent fixed  
 magnetic poles being turned to S.

Fig. 1

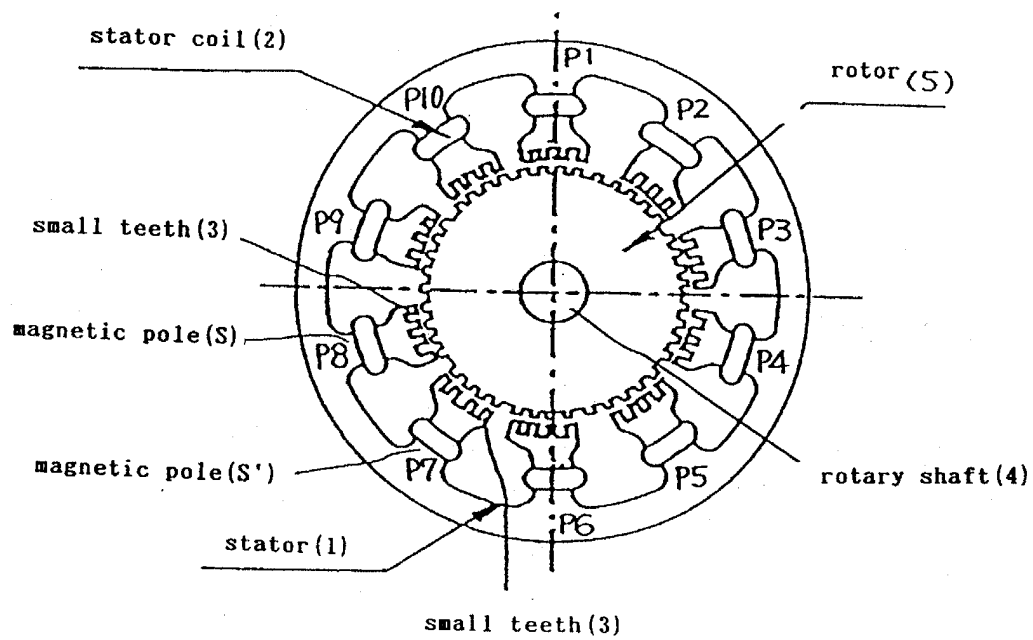


Fig. 2

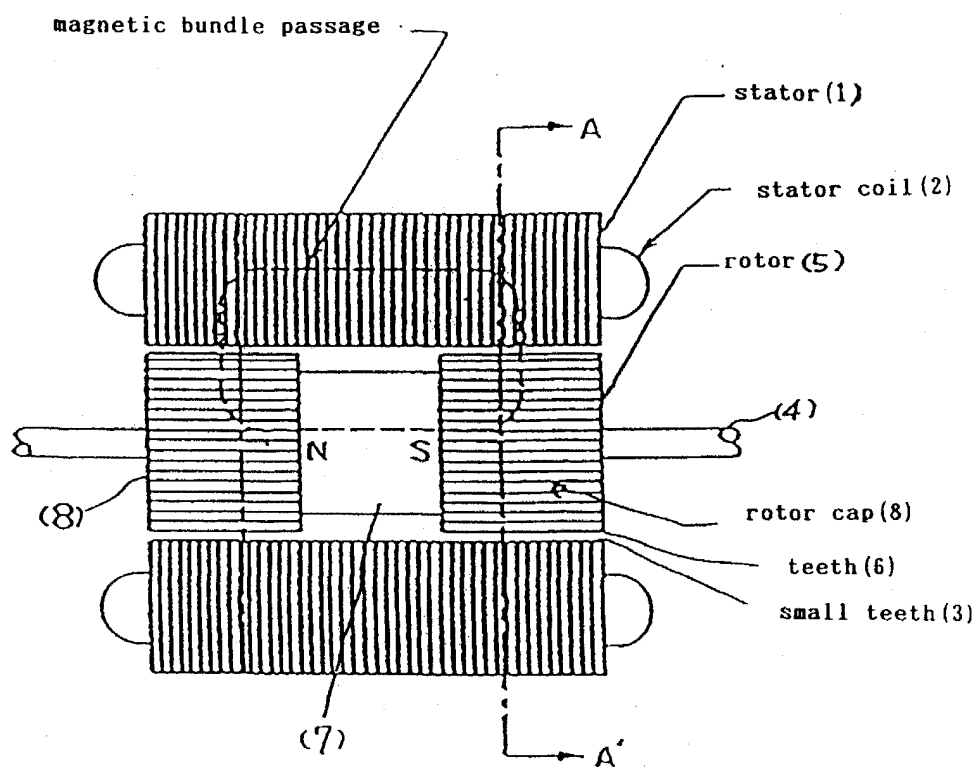
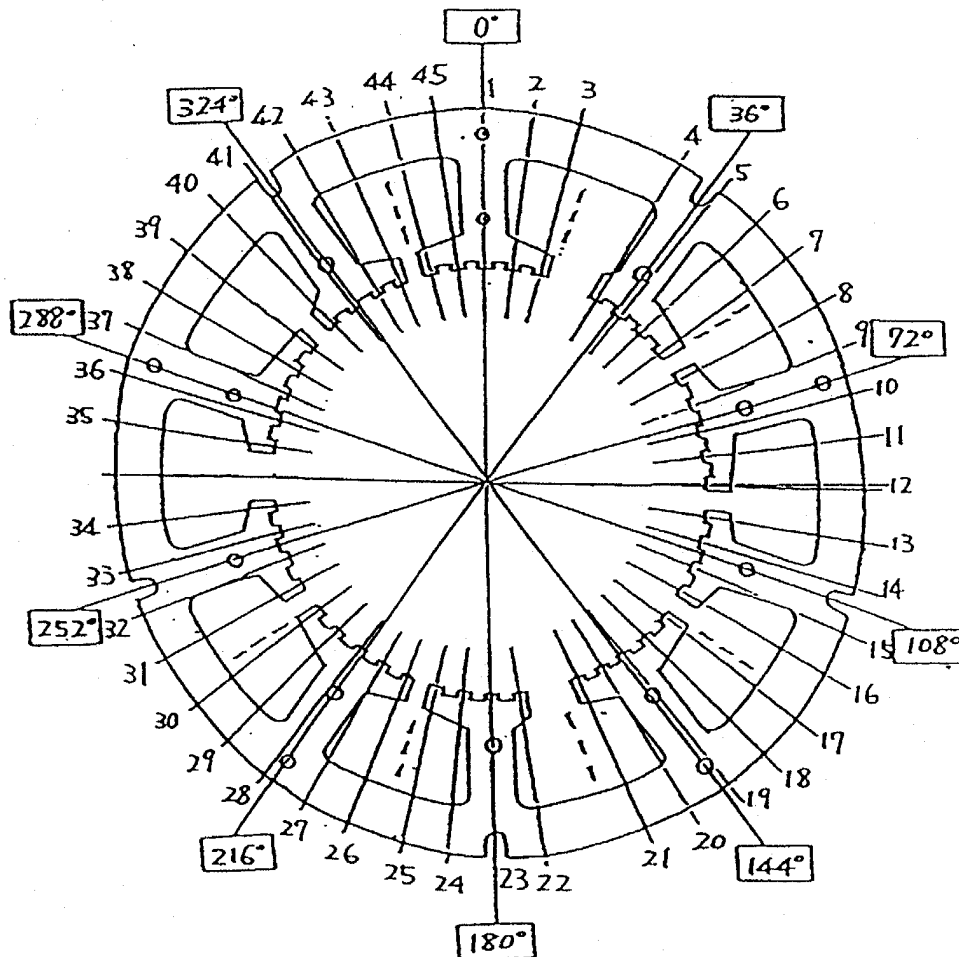


Fig. 3



STRUCTURE OF ASYMMETRIC STATOR

shift angle  $1/5 T_p$ , and  $N_r = 50$   $N_s = 45$   
 small slot having three intervals  
 small slot having seven intervals



Fig. 4

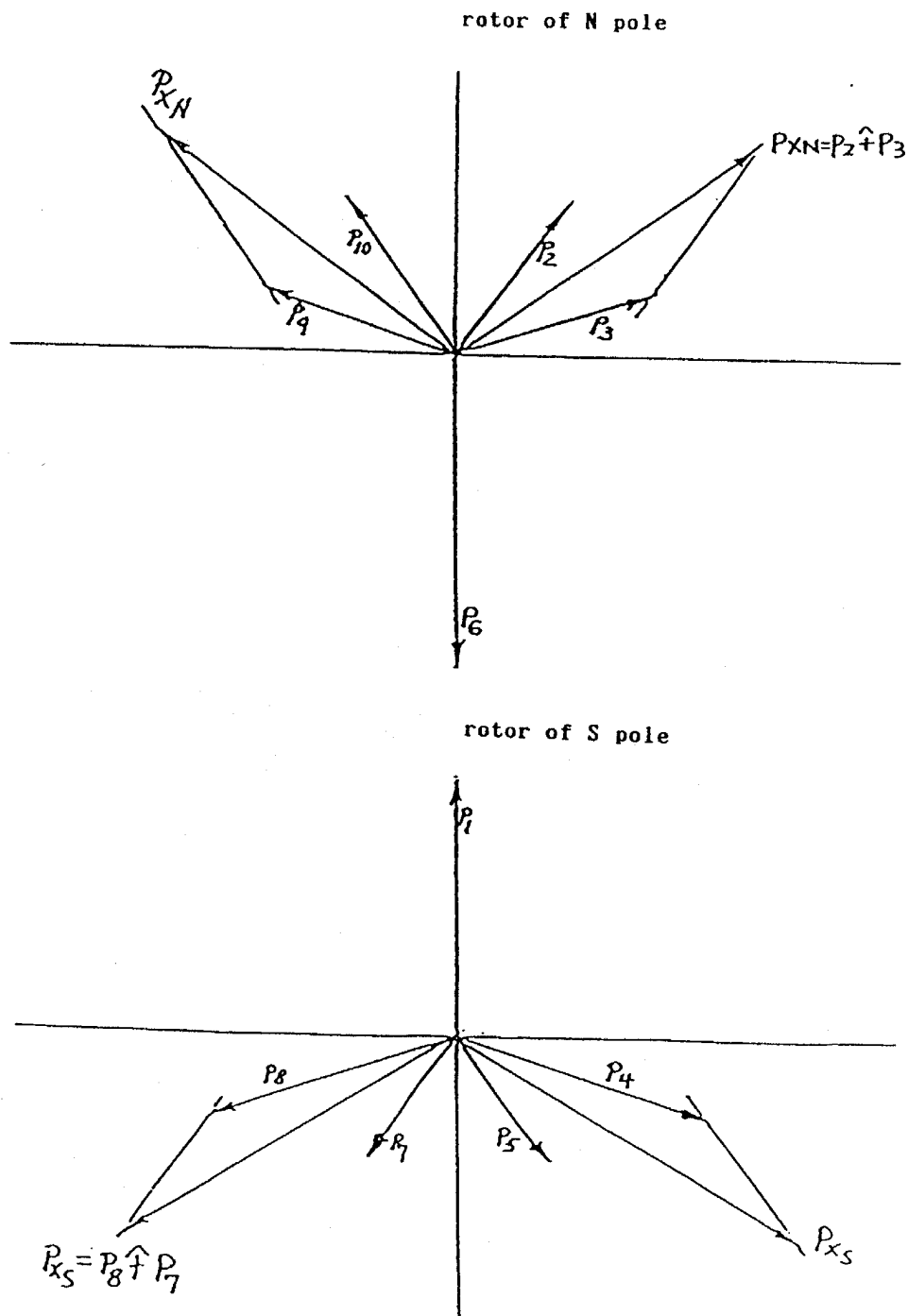


Fig. 5

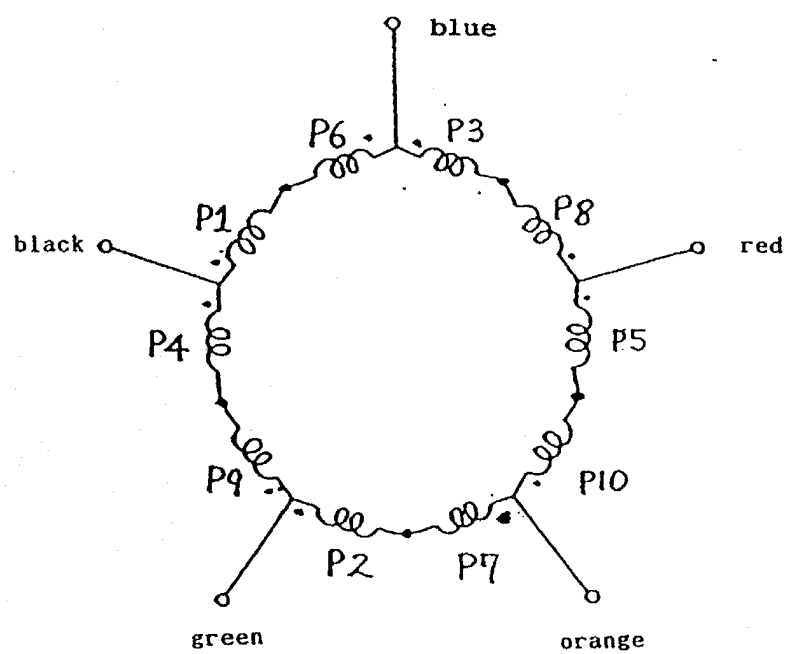


Fig. 6

POLE STEP	1	2	3	4	5	6	7	8	9	10
1	-	S	N	N	S	-	N	S	S	N
2	N	S	-	N	S	S	N	-	S	N
3	N	S	S	N	-	S	N	N	S	-
4	N	-	S	N	N	S	-	N	S	S
5	N	N	S	-	N	S	S	N	-	S
6	-	N	S	S	N	-	S	N	N	S
7	S	N	-	S	N	N	S	-	N	S
8	S	N	N	S	-	N	S	S	N	-
9	S	-	N	S	S	N	-	S	N	N
10	S	S	N	-	S	N	N	S	-	N

Fig. 7

POLE STEP	1	2	3	4	5	6	7	8	9	10
1	S	S	N	N	S	N	N	S	S	N
2	-	S	N	N	S	-	N	S	S	N
3	N	S	N	N	S	S	N	S	S	N
4	N	S	-	N	S	S	N	-	S	N
5	N	S	S	N	S	S	N	N	S	N
6	N	S	S	N	-	S	N	N	S	-
7	N	S	S	N	N	S	N	N	S	S
8	N	-	S	N	N	S	-	N	S	S
9	N	N	S	N	N	S	S	N	S	S
1 0	N	N	S	-	N	S	S	N	-	S
1 1	N	N	S	S	N	S	S	N	N	S
1 2	-	N	S	S	N	-	S	N	N	S
1 3	S	N	S	S	N	N	S	N	N	S
1 4	S	N	-	S	N	N	S	-	N	S
1 5	S	N	N	S	N	N	S	S	N	S
1 6	S	N	N	S	-	N	S	S	N	-
1 7	S	N	N	S	S	N	S	S	N	N
1 8	S	-	N	S	S	N	-	S	N	N
1 9	S	S	N	S	S	N	N	S	N	N
2 0	S	S	N	-	S	N	N	S	-	N

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP94/00140

## A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl<sup>5</sup> H02K37/04

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Int. Cl<sup>5</sup> H02K37/04, H02K37/00, H02K37/14

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Jitsuyo Shinan Koho 1926 - 1994

Kokai Jitsuyo Shinan Koho 1971 - 1994

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	JP, B2, 1-32748 (Oriental Motor Co., Ltd.), July 10, 1989 (10. 07. 89), Tables 2, 5, Figs. 1, 6 & US, A, 4385247	1
Y	JP, A, 61-185056 (Merck Japan Ltd.), August 18, 1986 (18. 08. 86), Figs. 2, 6, (Family: none)	1
Y	JP, U, 60-111382 (Mitsuba Electric Mfg. Co., Ltd.), July 27, 1985 (27. 07. 85), Fig. 1(b), (Family: none)	1

☒ Further documents are listed in the continuation of Box C.☐ See patent family annex.

\* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&amp;" document member of the same patent family

Date of the actual completion of the international search

May 27, 1994 (27. 05. 94)

Date of mailing of the international search report

June 14, 1994 (14. 06. 94)

Name and mailing address of the ISA/

Japanese Patent Office

Authorized officer

Facsimile No.

Telephone No.